

Revision of the Sampling Design for the Puget Sound Ambient Monitoring Program (PSAMP) Sediment Component

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[Editor's note: Figures for Dutch et al are located at the end of this document.]

Abstract

The Washington State Department of Ecology (Ecology)'s Marine Sediment Monitoring Team (MSMT) has been conducting long-term monitoring and regional surveys of sediment quality as a part of the Puget Sound Ambient Monitoring Program (PSAMP) since 1989, twice revising the sampling design to better meet the PSAMP goals and objectives. With assistance from the U.S. Environmental Protection Agency (EPA) and regional stakeholders, the program's probabilistic sampling design was recently refined using a spatially balanced random stratified survey design, and a revised list of sampling parameters. A nested set of sampling frames was defined that includes the entire Puget Sound basin, eight sediment sampling regions, 5 strata within each of the 8 regions, and several urban embayments for focused studies. They will be sampled on a rotational cycle, alternating 8 years of regional sampling with 2 years of focused embayment sampling or focused analyses. Results will be analyzed to estimate the spatial extent of degraded sediment quality (based on the sediment triad of toxicity, chemistry, and benthic infauna) in each annual study area. Data from each year will be analyzed and compared with previous results to identify temporal trends. A summary of the evolution of the PSAMP Sediment Component since its inception, and details of the current refinements to the study design are described in this presentation.

Introduction

The Puget Sound Ambient Monitoring Program (PSAMP) Sediment Component was developed in 1988 and first implemented in 1989 to provide a record of the condition of Puget Sound sediments, including baseline and long-term data on chemical contamination, toxicity, and benthic infaunal (Puget Sound Water Quality Authority 1988; Striplin 1988). Over time, the Sediment Component goals have been revised and refined to focus on determining both spatial and temporal trends in sediment quality, with the sampling design undergoing two evolutionary changes to better meet these goals.

The original Sediment Component sampling design consisted of sampling 34 core and 42 rotating "non-random" stations annually throughout Puget Sound for sediment chemistry, toxicity, and benthic infaunal community structure (Figure 1). Sampling stations were chosen to represent conditions at specific locations. With this non-random design, sampling results were used to characterize conditions at each station, but could not be extrapolated to the larger surrounding area; therefore spatial characterizations of sediment quality in different regions of Puget Sound were not possible. In 1995, the PSAMP program was reviewed, and it was recommended that changes be made to better address the objectives of determining the spatial status of and temporal trends in Puget Sound sediment quality (Shen 1995). Over the next few years, the program's goals and sampling design were revised and refined to meet these new objectives.

PSAMP/NOAA Sediment Monitoring Design

The first major revision to the PSAMP Sediment Component monitoring design was made in 1997. The original program was reduced to 10 stations (Figure 2), which are monitored for temporal trends in infauna annually and chemistry every fifth year. The details of this continuing PSAMP Sediment Component Temporal Trends element are described in the program's revised Quality Assurance Project Plan (Dutch et al., in preparation), and data collected from these 10 stations from 1989 through 2000 are summarized in Partridge et al. (in review).

The primary focus of the 1997 revision, however, was to develop a spatial monitoring element, which had been lacking previously. In 1997, a cooperative agreement was forged between the PSAMP Sediment Component and NOAA's National Status and Trends (NS&T) Program to conduct sediment sampling in Puget Sound based on the NS&T's Program probabilistic random stratified sampling design (i.e., spatial sediment monitoring; Long et al. 1996). Through the PSAMP/NOAA partnership, a sediment quality survey was conducted throughout Puget Sound to estimate the spatial extent of degraded conditions (Long et al. 1999, 2000, 2002, in review).

The PSAMP/NOAA sediment survey divided Puget Sound into 3 regions, including north, central, and south, sampled over 3 years (Figure 3). In an effort to achieve some spatial balance in sample placement throughout the study regions, each was divided into 33 relatively homogeneous strata (or polygons), with 3 or 4 randomly chosen stations allotted to each stratum. A total of 100 samples were collected annually, for a total of 300 samples over the 3 year period. The same suite of sediment quality triad parameters (i.e., chemical concentrations, laboratory test of toxicity, and benthic infauna analyses) were measured at each station. The primary products of this 3-year spatial monitoring effort was the generation of spatial sediment quality baseline values for the triad parameters in each survey area (i.e., not just the points sampled). Analyses were completed to develop:

- Spatial patterns maps which displayed stations where sediments were contaminated relative to national guidelines and/or state sediment quality standards, and/or where toxicity was recorded, and/or where the benthos was degraded.
- Spatial extent calculations for both contamination and toxicity expressed as both size of the area in which specific critical values were exceeded and as the percentages of the total survey area.
- Development of a sediment quality triad index, a “weight-of-evidence” index used to rank sediment quality in the various study regions.

Results from these studies were summarized in the 2002 Puget Sound Update (PSWQAT 2002), 3 annual reports (Long et al. 1999, 2000, 2002), and a 3-year summary report (Long et al. in review). Reports and data are available on Ecology’s Marine Sediment Monitoring Team’s website (http://www.ecy.wa.gov/programs/eap/mar_sed/msm_intr.html).

PSAMP/EMAP Sediment Monitoring Design

As the sediment monitoring partnership with NOAA was concluding in 1999, the MSMT entered into a new partnership with EPA to implement their nationwide Environmental Monitoring and Assessment Program’s (EMAP) coastal estuaries monitoring survey. The EMAP program is similar to the NS&T sediment monitoring program that NOAA brought to Puget Sound, but is broader in its scope of parameters, and added some refinements to NOAA’s probabilistic random stratified sampling design. With assistance and training from EPA statisticians, the MSMT is conducting the Washington component of the Pacific Coast EMAP survey, and has also incorporated the following “EMAP-style” design elements and refinements into the PSAMP Sediment Component’s monitoring program:

- The PSAMP/EMAP sediment monitoring design employs a spatial balancing algorithm to ensure a more even distribution of stations throughout the chosen study region.
- A series of nested sampling populations and subpopulations have been defined for the PSAMP/EMAP sediment monitoring program. These study areas replace the north, central, south sampling regions chosen for the PSAMP/NOAA study. They are better aligned with Puget Sound’s geographic, hydrologic, and anthropogenic features, and better meet PSAMP’s reporting needs.
- A minimum of 30 samples per year will be collected from each sampling population or subpopulation, a statistically derived minimum sampling effort that should ensure adequate statistical power to accurately describe the sediment quality of each study area.
- Both spatial and temporal element measurements can be made with this design through the calculation of cumulative distribution functions and the 95% confidence intervals around them.

Puget Sound Sampling Frames

A set of four nested sampling frames was created for the revised PSAMP/EMAP sampling program, based on a spatially balanced random stratified sampling design. The four frames are reporting units for which Puget Sound sediment monitoring data will be summarized. Estimates will be generated for the spatial extent of chemical contamination and toxicity, condition of the benthic infaunal communities, as well as overall sediment quality, for each sampling frame. The four frames include the following:

- Puget Sound (Figure 4)—This is the entire Puget Sound study population defined by the Sediment Monitoring Team and encompasses all other study frames and study subpopulations.
- Eight (8) Puget Sound sediment monitoring regions (Figure 5)—These regions are defined by hydrologic and bathymetric features and coincide with the Puget Sound basins identified and agreed upon by PSAMP Steering Committee members as appropriate areas for research and reporting for all PSAMP components.
- Five (5) Puget Sound sediment monitoring strata (Figure 6)—These strata were defined by the MSMT by categorization of the geographic and anthropogenic features of each.
- “Focus” embayments—Periodically, boundaries will be defined around relatively small scaled “focus” embayments of interest within the Puget Sound study population. Upon sampling and analysis of 30 random stations from each new area, the sediment quality for the embayment of interest can be spatially defined.

Baseline Data, Rotational Sampling Cycle, Reporting Schedule, and Products

A 10-year rotational sampling cycle and reporting schedule have been developed for the nested series of sampling populations (Table 1). During 2002 and 2003, sampling was conducted in the San Juan Archipelago, the eastern Strait of Juan de Fuca, and the Admiralty Inlet regions, because these areas were not sampled adequately or at all during the 1997-1999 PSAMP/NOAA partnership. Characterization of these regions will complete the baseline of spatial monitoring data against which future sediment data can be compared. Sediment monitoring will then be conducted on a 10-year rotational cycle, with 2 years of either focused study or intensive embayment surveys alternating with 8 years of sampling which cycles through the 8 sediment monitoring regions. This sampling regime will result in comparison of baseline spatial sediment quality data for each region with newly collected data on a 10-year rotational cycle. Because the concentrations and biological effects of toxicants in sediments tend to change slowly over time, a 10-year sampling interval for each region should be adequate to identify significant temporal trends. A reporting schedule is depicted at the bottom of Table 1. Regional and focus study reports will be generated annually, while whole sound/strata reports will be generated every 10 years.

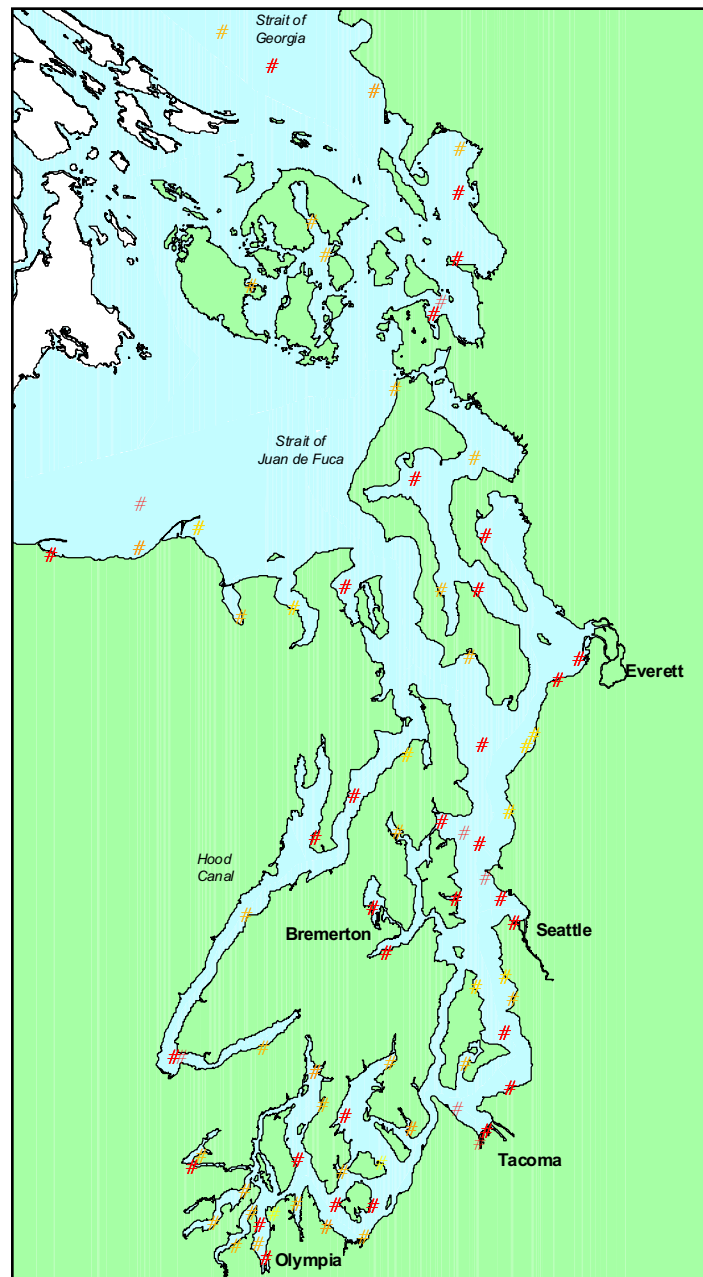
As with the PSAMP/NOAA work, spatial sediment quality reporting will again include generation of spatial pattern maps, spatial extent calculations for chemistry and toxicity, and the Sediment Quality Triad Index values (Long et al. 1999, 2000, 2002, in progress). Spatial extent calculations will be generated via cumulative distribution function (CDF) curves with 95% confidence bounds (example—Figure 7). These curves describe the spatial distribution of the data collected for any given parameter measured throughout the study area, and can be used to estimate the percentage of the study area which falls above or below critical values for each parameter. For example, 8% of the study area depicted in Figure 7 exceeded the WA State Sediment Management Standard for Mercury (0.41 mg/kg dry weight). In addition to the spatial reporting component, there is a temporal element to the study design. Calculation of the 95% confidence bands around the estimates provides a means of determining variance. The estimates generated with the CDFs and their confidence intervals can be compared between sampling periods for each study area. Statistically significant shifts in the estimated areas affected and the variance around the estimates can be used to indicate whether a parameter increased, decreased, or did not change in the size of the area affected.

Summary

Since its inception in 1989, the PSAMP Sediment Monitoring Component has evolved several times. The original PSAMP design, conducted from 1989 to 1996, consisted of repeated sampling of non-randomly selected stations annually. This design provided characterization of each station on an annual basis and temporal comparisons, but did not allow evaluation of the surrounding area. Through the 1997-1999 partnership with the NOAA NS&T sediment bioeffects monitoring program, a spatial element was added to the PSAMP design via adoption of a probabilistic random stratified sampling design. Sediment quality measurements collected from 3 to 4 stations in each of 99 strata allowed the spatial extent of sediment contamination and toxicity to be characterized for northern, central, and southern regions defined for Puget Sound. Most recently (2002), the PSAMP Sediment Component was refined through assistance and collaboration from EPA and regional stakeholders, and includes both a spatial and temporal element. The program incorporates a spatially-balanced probabilistic random stratified sampling design, with a nested set of 4 sampling frames, allowing spatial characterization of sediment quality throughout Puget Sound. A 10-year rotational sampling cycle provides temporal comparison of the defined Puget Sound sediment monitoring regions. Details of the history and evolution of this program, and the current design are summarized in detail in the program's Quality Assurance Project Plan (Dutch et al., in preparation).

Literature Cited

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(● = 34 core stations. ● = 42 rotating stations)

Figure 1. PSAMP Sediment Component Historical Sampling Design (1989 - 1996). The 34 core stations were sampled annually, while the 42 rotating stations (3 groups of 14 stations in northern, central, and southern Puget Sound) were sampled on a 3-year rotational cycle.

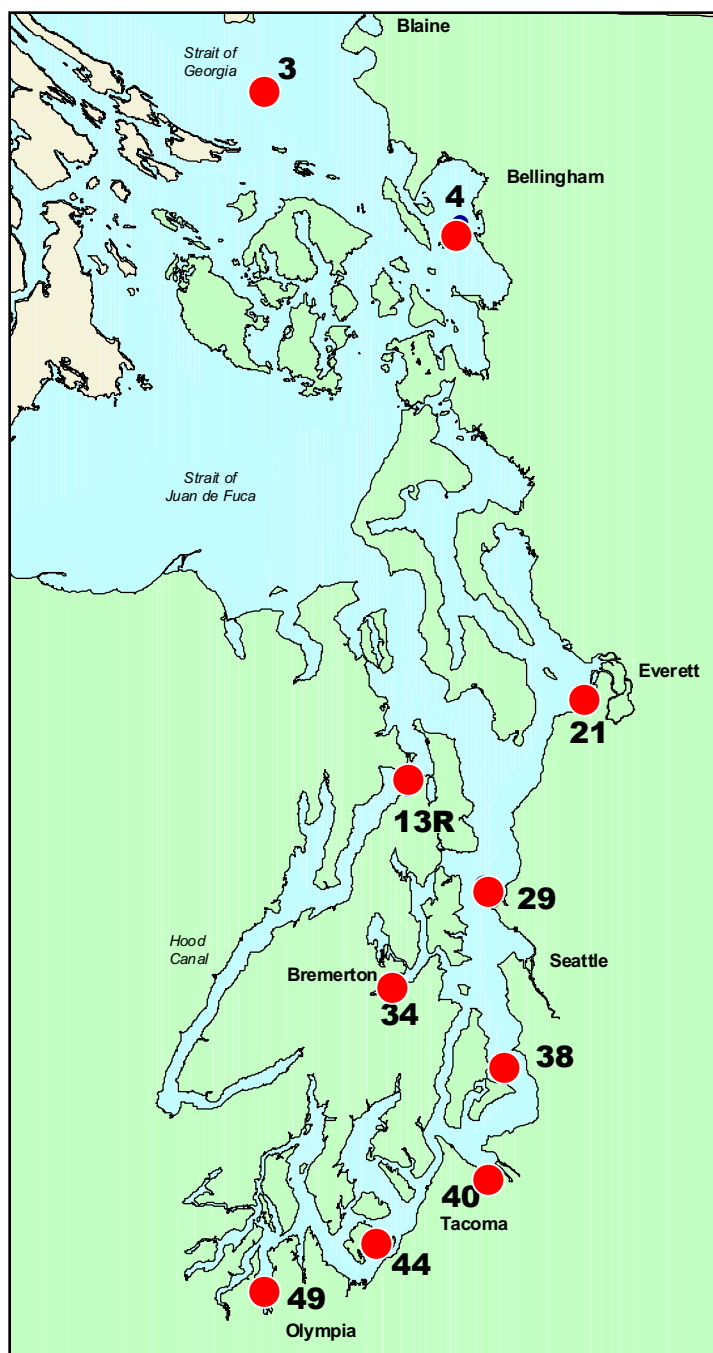


Figure 2. PSAMP Sediment Component Temporal Trends Sampling Design (1997 through present). Ten of the historical stations are sampled annually for benthos, TOC, and grain size; every fifth year for chemistry.

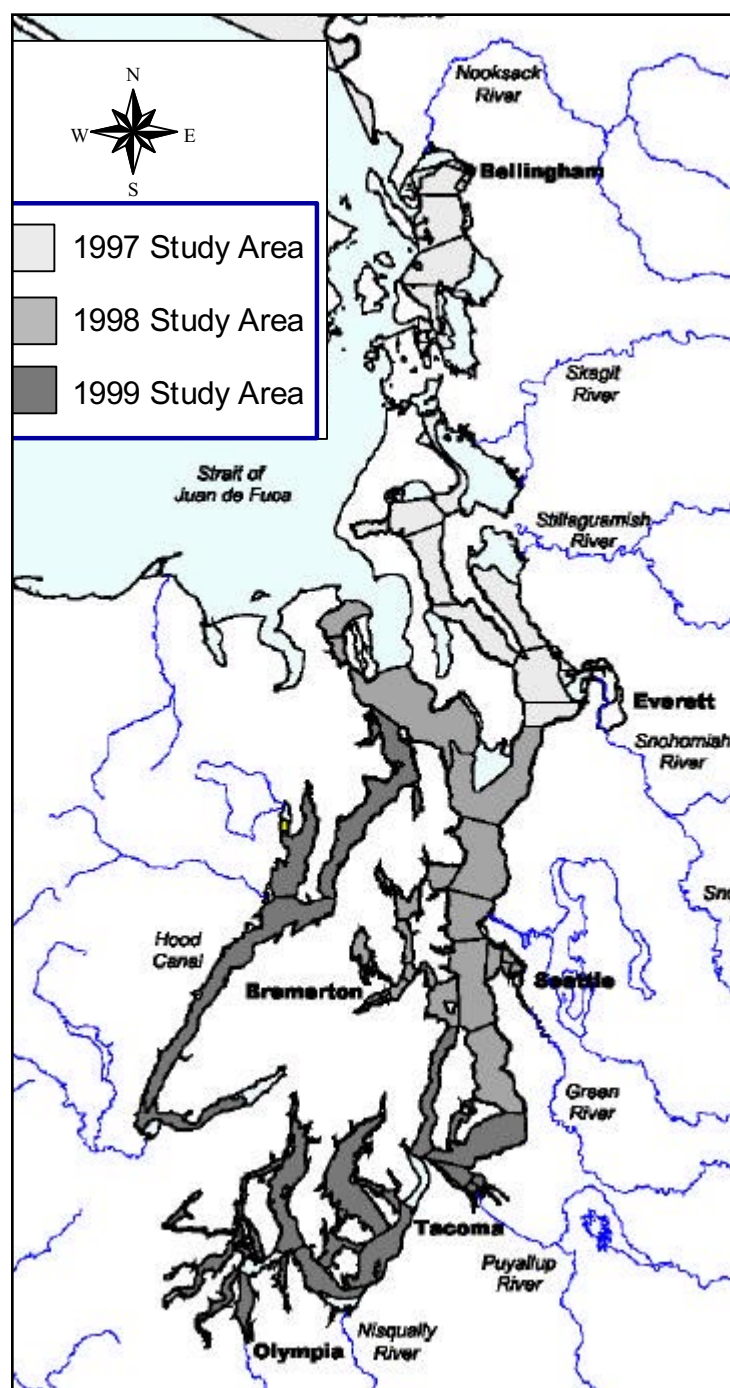


Figure 3. Map of the Puget Sound study area for the PSAMP/NOAA Sediment Monitoring survey (1997-1999).

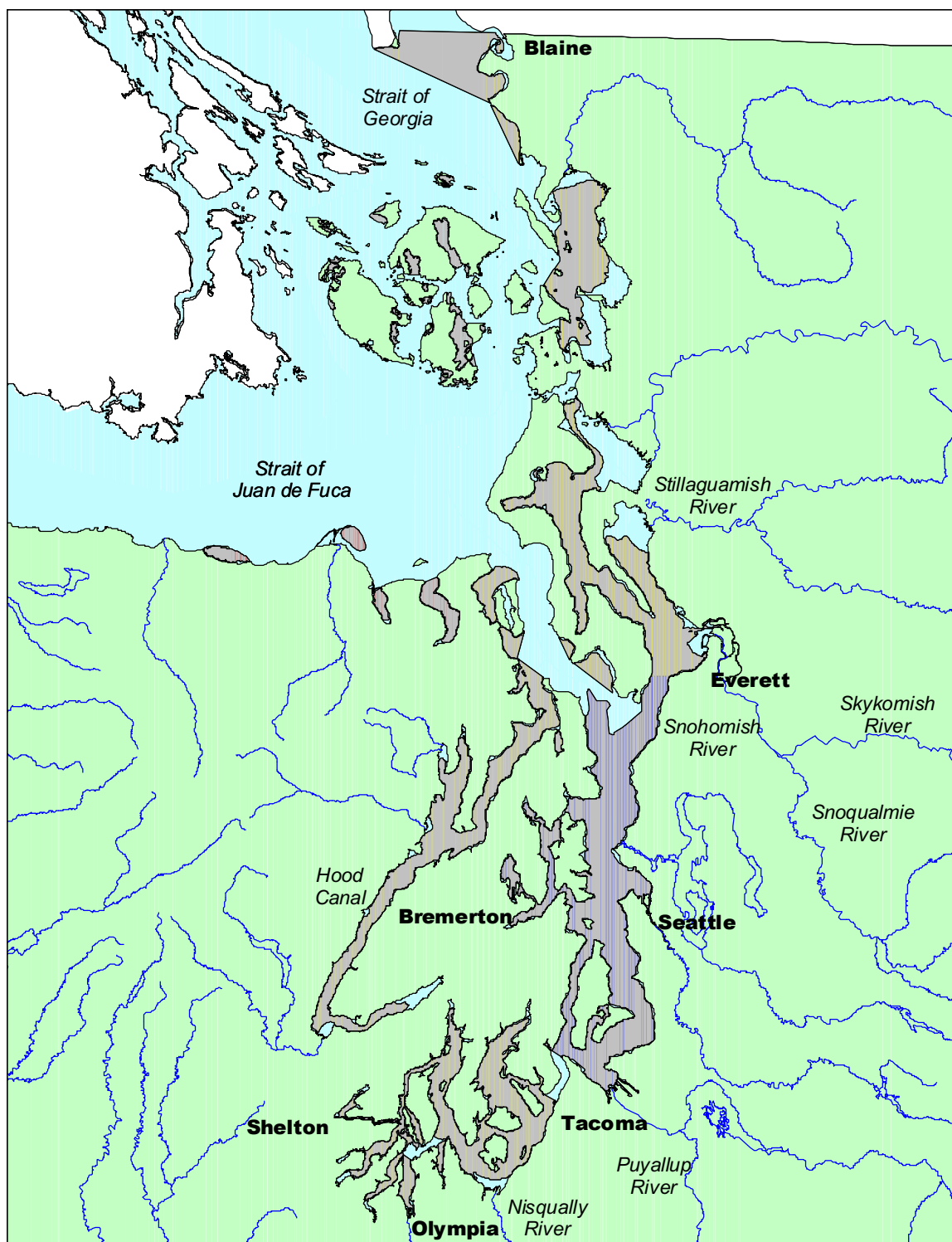


Figure 4. Map of the “whole” Puget Sound study area for the PSAMP/EMAP Sediment Monitoring survey (2002 and future).

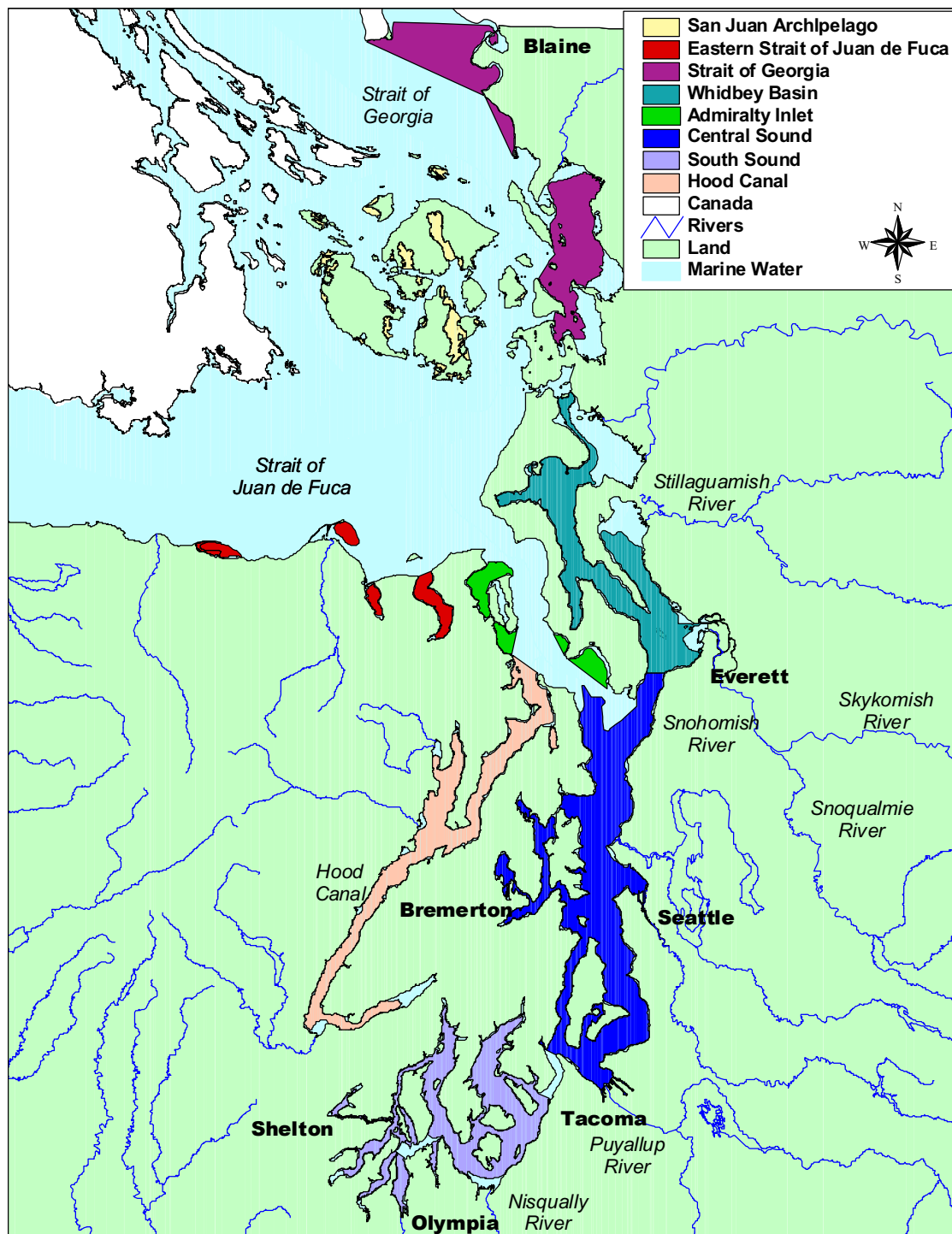


Figure 5. Map of the 8 Puget Sound sediment monitoring “regions” defined for the PSAMP/EMAP Sediment Monitoring survey (2002 and future).

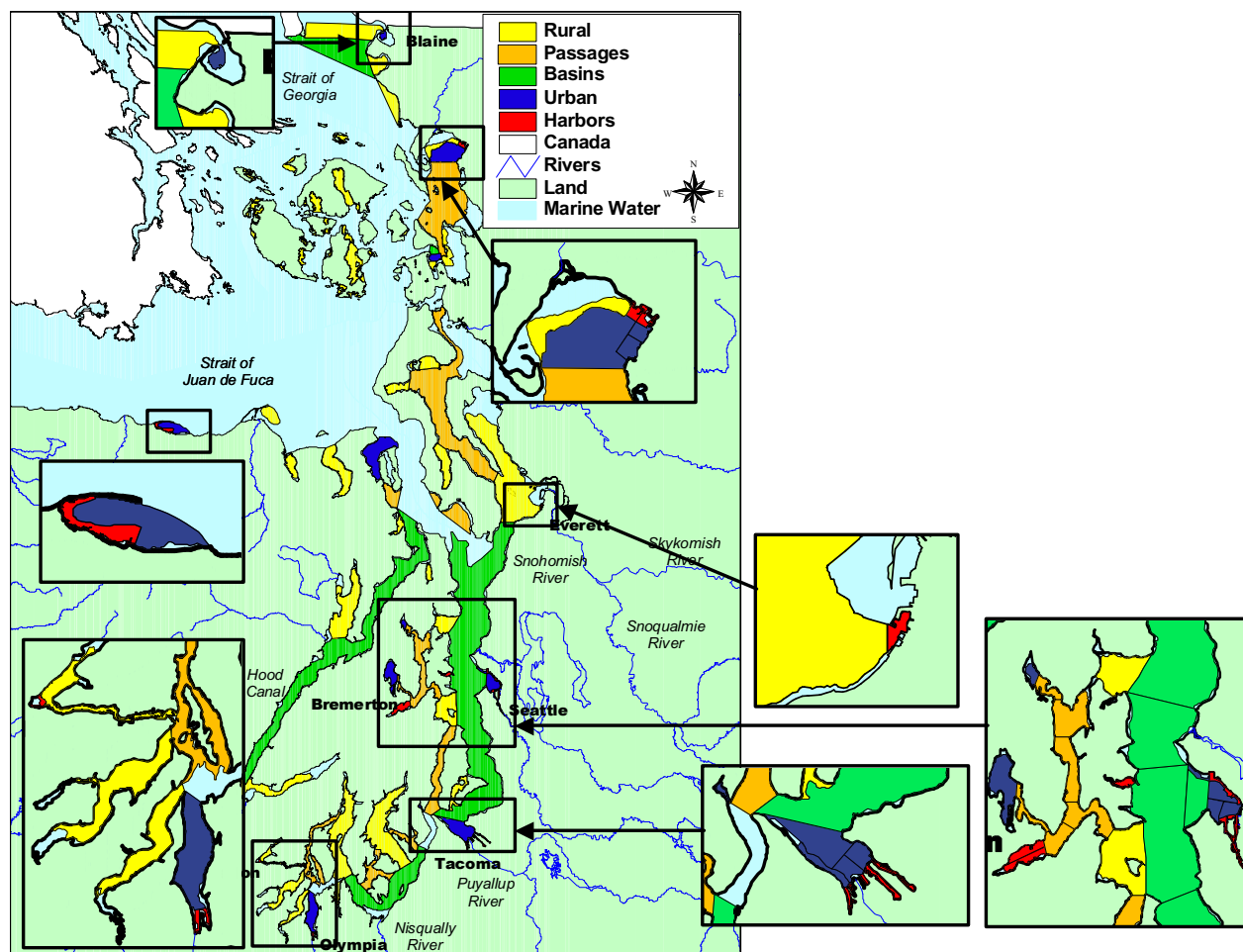


Figure 6. Map of the 5 Puget Sound sediment monitoring “strata” defined for the PSAMP/EMAP Sediment Monitoring survey (2002 and future).

Sediment Mercury Concentration

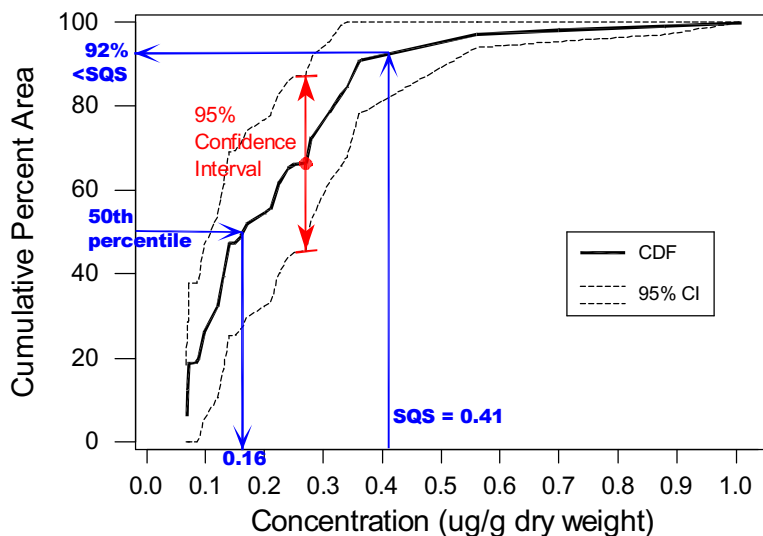


Figure 7. Example of a Cumulative Distribution Function (CDF) curve and 95% confidence interval (red) for mercury concentration in sediments. Note (blue) that 50% of the population has a mercury value ≥ 0.16 ug/g dry wt., while 8% of the population has mercury values exceeding the Washington State Sediment Quality Standard (SQS) of 0.41 ug/g dry wt.

Table 1. PSAMP/EMAP 10-year rotational sediment monitoring and reporting schedule (2004-2013). Rotation through 8 regions (8 years) and focus studies (2 years).

2004-2013 sampling schedule (10 year rotation through 8 regions and focus studies)											
Region	Year Sampled (minimum no. samples required)										
	2002-2003*	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
San Juan Archipelago, Eastern Strait of Juan de Fuca, Admiralty Inlet	90										90
Strait of Georgia				30							
Whidbey Basin					30						
Central Sound (north)						30					
Central Sound (south)							30				
South Sound								30			
Hood Canal									30		
focus studies		30	30								
Reporting Schedule											
regional		x		x	x	x	x	x	x	x	
whole sound/strata		x									x
focus study			x	x							
* with 1997-1999 PSAMP/NOAA, completes the "whole sound" spatial sampling baseline											